

Article

Making Decisions on the Development of County-Level Agricultural Industries through Comprehensive Evaluation of Environmental and Economic Benefits of Agricultural Products: A Case Study of Hancheng City

Chen Lu ¹, Huaizhou Wang ², Xue Li ¹ and Zhiyuan Zhu ^{2,*}

¹ College of Bioengineering, Yangling Vocational and Technical College, Yangling 712100, China; luchen1802@163.com (C.L.); LiXueZiMo2024@163.com (X.L.)

² College of Agronomy, Northwest A&F University, Yangling 712100, China; huaizhou@nwsuaf.edu.cn

* Correspondence: zhuzhiyuan@nwsuaf.edu.cn

Abstract: This study aims to provide a scientific basis for the development of county-level agricultural industries through a comprehensive evaluation of the environmental and economic benefits of agricultural products. Focusing on Hancheng City in Shaanxi Province, this paper calculates and analyzes the carbon emission intensity per unit output value and the economic benefits of major agricultural products, assessing their comprehensive advantage indices. The research methods include data collection, data processing, and model construction, utilizing a bi-factor matrix analysis to explore the balance between environmental sustainability and economic profitability of different agricultural products. The results indicate that pepper and vegetables have the highest comprehensive advantages, demonstrating significant economic and environmental benefits, while soybeans show lower comprehensive advantages, requiring improvements in cultivation techniques and management practices. Based on the research findings, this paper proposes policy and management recommendations for different agricultural products, including focusing on the development of high-comprehensive-advantage products, improving cultivation techniques for low-comprehensive-advantage products, promoting green agricultural technologies, establishing a carbon footprint monitoring system for agricultural products, and strengthening agricultural infrastructure construction. The study's conclusions provide theoretical support and practical guidance for the agricultural development strategies of Hancheng City and similar regions, contributing to the achievement of sustainable agricultural development and carbon reduction goals.

Keywords: comprehensive advantage index; carbon emission intensity; agricultural sustainability; economic benefits



Citation: Lu, C.; Wang, H.; Li, X.; Zhu, Z. Making Decisions on the Development of County-Level Agricultural Industries through Comprehensive Evaluation of Environmental and Economic Benefits of Agricultural Products: A Case Study of Hancheng City. *Agriculture* **2024**, *14*, 888. <https://doi.org/10.3390/agriculture14060888>

Academic Editors: Petru Alexandru Vlaicu, Arabela Elena Untea and Teodora Popova

Received: 21 May 2024

Revised: 3 June 2024

Accepted: 3 June 2024

Published: 4 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The escalating urgency of addressing global climate change has placed significant emphasis on the need to control and reduce carbon emissions across all sectors. Agriculture, as a substantial source of greenhouse gas emissions, plays a critical role in this effort. It is estimated that agricultural activities contribute approximately 14% of the total global greenhouse gas emissions, highlighting the necessity of implementing effective carbon reduction strategies within this sector. The challenge, however, lies in balancing the need for carbon reduction with the imperative of maintaining economic viability in agricultural production. This dual objective necessitates a comprehensive evaluation of the environmental and economic benefits of agricultural products to inform the development of county-level agricultural industries.

A considerable body of literature has examined various aspects of agricultural carbon emissions and economic benefits, providing valuable insights that inform this study. Existing studies indicate that the primary sources of agricultural carbon emissions include

soil management, fertilizer use, irrigation, mechanical operations, and livestock rearing [1]. The carbon emission intensity of different agricultural products varies significantly, necessitating detailed evaluations to develop effective carbon reduction strategies. For example, Lal highlights the significant carbon sequestration potential of soil management practices, while West and Marland [2] focus on the carbon costs of agricultural practices, emphasizing the need for sustainable farming techniques.

Furthermore, improving agricultural efficiency can lead to substantial reductions in greenhouse gas emissions [3]. This aligns with findings advocating for the adoption of high-yield practices to meet future food demands while minimizing environmental impacts [4,5]. These studies collectively underscore the importance of optimizing both economic and environmental performance in agricultural practices. Economic evaluations of agricultural production have also been extensively studied. The concept of comparative advantage, fundamental in understanding the economic benefits of different agricultural products, has been well explored [6]. Recent studies further explore the implications of comparative advantage in modern agricultural contexts, emphasizing the need for regions to specialize in crops where they hold an economic edge [7,8]. This principle is crucial for developing strategies that enhance the economic viability of agriculture while addressing environmental concerns.

However, while many studies focus on evaluating either environmental or economic benefits, there is a notable gap in comprehensive assessments that consider both aspects simultaneously [9,10]. The integration of environmental and economic evaluations is essential for developing holistic agricultural policies that support sustainable development. Efforts to bridge this gap highlight the need for policies that incentivize sustainable practices without compromising economic productivity [11–14]. In the context of China, several studies have focused on the specific challenges and opportunities within the agricultural sector. Research has examined the carbon footprints of various agricultural products in China, identifying significant regional variations and suggesting targeted strategies for carbon reduction [15–17]. Similarly, economic implications of agricultural practices in China have been explored, emphasizing the need for region-specific strategies that consider both economic and environmental factors [18–20].

Hancheng City is located in the eastern part of Shaanxi Province under the jurisdiction of Weinan City. Positioned in the middle reaches of the Yellow River, Hancheng enjoys a mild climate and fertile soil, making it a key agricultural production base in Shaanxi Province. The city's agricultural production includes grain crops, economic crops, and livestock, with high-value products such as pepper, apples, and vegetables [21,22]. In recent years, with the development of ecological agriculture, Hancheng has actively promoted green technologies and low-carbon agricultural practices, laying a solid foundation for sustainable agricultural development.

This study aims to address these gaps by providing a comprehensive evaluation of the environmental and economic benefits of various agricultural products in Hancheng City. By calculating and analyzing the carbon emission intensity per unit output alongside the economic benefits of these products, the study evaluates their composite advantage indices. These indices, combined with a bi-factor matrix analysis, enable an exploration of the balance between environmental sustainability and economic profitability. The insights gained from this evaluation are intended to offer theoretical support and practical guidance for the strategic development of agricultural industries in Hancheng City and potentially other regions.

2. Materials and Methods

2.1. Comprehensive Comparative Advantage Measurement Method

The comprehensive comparative advantage measurement method is commonly used for analyzing the regional differences in the comparative advantage of planting and breeding industry products. It typically includes the Efficiency Comparative Advantage Index (ECAI), the Scale Comparative Advantage Index (SCAI), and the Comprehensive Compar-

ative Advantage Index (CCAI). These indices are used to measure the efficiency advantage of regional agricultural product production, primarily reflecting the degree of scale and specialization in production. This method is commonly used to compare the same product across different regions or different products within the same region.

The Efficiency Comparative Advantage Index examines the comparative advantage of a specific industry in a particular region from the perspective of optimal resource utilization. The Scale Comparative Advantage Index considers the comparative advantage of an industry from the perspective of achieving better professional standard production through large-scale production. Agricultural production efficiency is related to the size of its production scale. When the scale of agricultural production is small, the efficiency of agricultural production gradually increases with the expansion of the scale within a certain stage. After reaching a certain scale, agricultural production efficiency stabilizes at a relatively stable level and then declines. Therefore, we cannot rely solely on the Efficiency Advantage Index to determine whether an industry has a regional advantage.

$$EAI_{ij} = \frac{AP_{ij}/AP_i}{AP_j/AP} \quad (1)$$

$$SAI_{ij} = \frac{GS_{ij}/GS_i}{GS_j/GS} \quad (2)$$

$$AAI_{ij} = \sqrt{EAI_{ij} \times SAI_{ij}} \quad (3)$$

EAI_{ij} , SAI_{ij} , AAI_{ij} represents the efficiency comparative advantage coefficient, scale comparative advantage index and comprehensive comparative advantage index of crop i and county j , respectively. AP_{ij} represents the yield per unit area of j agricultural products in county i ; AP_i represents the average yield per unit area of all agricultural products in region i ; AP_j represents the average yield per unit area of j crops in Weinan; AP represents the average yield per unit area of all crops in Weinan. GS_{ij} represents the sown area of j crops in county i ; GS_i represents the total sown area of crops in county i ; GS_j represents the total sown area of j crops in Weinan City; and GS represents the total sown area of crops in Weinan City. When $AAI_{ij} > 1$, it indicates that compared with the whole Weinan city, i region j crops have a comprehensive comparative advantage, otherwise there is no comprehensive comparative advantage.

Due to the differences in production between animal husbandry and planting, the comparative advantage of livestock products is calculated by combining production efficiency and scale, and directly calculating the comprehensive comparative advantage index using the total production volume.

$$AAI_{ij} = \frac{A_{ij}/A_i}{A_j/A} \quad (4)$$

In Formula (4), A_{ij} the yield of seed livestock products in i county (city) j , A_i is the yield of all livestock products in i county j , A_j is the yield of seed livestock products in Weinan City j , and A is the yield of all livestock products in Weinan City. $AAI_{ij} > 1$, i county (city) j breeding products have comparative advantage; $AAI_{ij} < 1$, i county (city) j breeding products do not have comparative advantage; the greater the product, the stronger the comparative advantage.

2.2. Calculation of Carbon Emissions

According to the IPCC National Greenhouse Gas List Guide, regarding the current situation of agricultural development in Hancheng city, referring to the research results of relevant scholars, the carbon source factors, and the corresponding carbon emission

coefficient are selected to construct the agricultural carbon emission calculation model. The specific formula is as follows:

$$E = \sum e_i = \sum c_i \times f_i \times T_i \quad (5)$$

$$EI = \frac{E}{CA} \quad (6)$$

where E is agricultural carbon emission in tCO_2 ; e_i is carbon emission of carbon source factor; c_i is input (production) of each carbon source factor; f_i is carbon emission factor; and T_i is conversion factor (see Table 1). Different greenhouse gases are all converted to CO_2 emissions. EI is the agricultural carbon emission intensity, tCO_2 /ten thousand yuan; CA is the total output value of agriculture and animal husbandry.

Table 1. Carbon emission coefficient table.

Carbon Source	Greenhouse Gas	Carbon Emission Coefficient	Conversion Factor
Wheat	CO_2	0.75 kg/kg	1
Corn	CO_2	0.48 kg/kg	1
Soybeans	CO_2	3.36 kg/kg	1
Potatoes	CO_2	0.81 kg/kg	1
Rapeseed	CO_2	1.4 kg/kg	1
Vegetables	CO_2	9073.95 kg/ha	1
Apples	CO_2	2440.5 kg/ha	1
Pepper	CO_2	1210 kg/ha	1
Cattle	CH_4	57 kg/head	25
	N_2O	1.34 kg/head	298
Sheep	CH_4	5.16 kg/head	25
	N_2O	0.33 kg/head	298
Pigs	CH_4	4.5 kg/head	25
	N_2O	0.53 kg/head	298
Poultry	CH_4	0.02 kg/bird	25
	N_2O	0.02 kg/bird	298

Note: The above-mentioned carbon emission coefficients for planting include carbon emissions from agricultural materials (fertilizers, pesticides, and agricultural films), carbon emissions from agricultural machinery power conversion, and soil N_2O emissions converted to carbon emissions. The carbon emission coefficients for livestock breeding include enteric CH_4 emissions, CH_4 emissions from manure management, and N_2O emissions.

2.3. LMDI Model

Drawing on previous research on carbon emission factors [18–20], this article presents the following transformation of agricultural carbon emissions:

$$E = \frac{E}{PGDP} \times \frac{PGDP}{AGDP} \times \frac{AGDP}{GDP} \times \frac{GDP}{TP} \times \frac{TP}{P} \times P \quad (7)$$

$$EI = \frac{E}{PGDP}, AI = \frac{PGDP}{AGDP}, IS = \frac{AGDP}{GDP}, EDL = \frac{GDP}{TP}, URB = \frac{TP}{P} \quad (8)$$

In Equations (7) and (8), E , $PGDP$, $AGDP$, GDP , TP , and P respectively represent agricultural carbon emissions, the sum of crop and animal husbandry output, the total output value of agriculture, animal husbandry, fishery and forestry, the total regional economic output value, the total regional population, and the total rural population. EI , AI , IS , EDL , URB , and P respectively represent agricultural production efficiency, agricultural industry

structure, overall industrial structure of Hancheng City, regional economic development level, urbanization, and rural population, reflecting the influencing factors of agricultural carbon emissions. This article uses the sum decomposition method of LMDI to decompose the influencing factors of agricultural carbon emissions from base period (E_0) to time t (E_t), as follows:

$$\Delta E = E_t - E_0 = \Delta EI + \Delta AI + \Delta IS + \Delta EDL + \Delta URB + \Delta P \quad (9)$$

Among them, t represents time t , 0 represents base period time, and ΔE represents the change in agricultural carbon emissions from base period to time t . ΔEI , ΔAI , ΔIS , ΔEDL , ΔURB , and ΔP respectively represent the contribution values of agricultural production efficiency, agricultural industrial structure, industrial structure, regional economic development level, urbanization, and rural population to the changes in agricultural carbon emissions from base period to time t , namely the influencing factors of agricultural carbon emissions. According to the decomposition method of LMDI, the calculation formulas for ΔEI , ΔAI , ΔIS , ΔEDL , ΔURB , and ΔP can be obtained:

$$\Delta EI = \sum \frac{E_t - E_0}{\ln E_t - \ln E_0} (\ln EI_t - \ln EI_0) \quad (10)$$

$$\Delta AI = \sum \frac{E_t - E_0}{\ln E_t - \ln E_0} (\ln AI_t - \ln AI_0) \quad (11)$$

$$\Delta IS = \sum \frac{E_t - E_0}{\ln E_t - \ln E_0} (\ln IS_t - \ln IS_0) \quad (12)$$

$$\Delta EDL = \sum \frac{E_t - E_0}{\ln E_t - \ln E_0} (\ln EDL_t - \ln EDL_0) \quad (13)$$

$$\Delta URB = \sum \frac{E_t - E_0}{\ln E_t - \ln E_0} (\ln URB_t - \ln URB_0) \quad (14)$$

$$\Delta P = \sum \frac{E_t - E_0}{\ln E_t - \ln E_0} (\ln P_t - \ln P_0) \quad (15)$$

3. Results

3.1. Economic Benefit Analysis of Various Agricultural Products

3.1.1. Analysis of Inter-Annual Changes in Comparative Advantage of Major Crops in Hancheng City

This section applies the production data of major agricultural products in Hancheng City from 2014 to 2020, using the comprehensive advantage index method to measure the comparative advantages of agricultural products such as grains (wheat, corn, beans, potatoes), oilseeds (rapeseed), vegetables, and fruits in Hancheng City.

According to Figure 1, we can conclude that the Efficiency Comparative Advantage Index (ECAI) for beans, vegetables, and fruits in Hancheng City is greater than 1, indicating an efficiency comparative advantage. However, the ECAI values for grains and oilseeds are all less than 1, indicating no efficiency comparative advantage. The ECAI for beans has been greater than 1 over the seven years and shows a slow upward trend, suggesting that the advantage in bean production can be utilized to increase the production of bean crops. The ECAI for vegetables and fruits has been less than 1 in recent years, indicating a comparative disadvantage, which suggests the need to optimize industrial technology levels and improve crop production efficiency. The ECAI for potatoes has shown a continuous upward trend, indicating that the cultivation technology level for potato crops in Hancheng City is continuously improving, showing great potential for future agricultural cultivation.

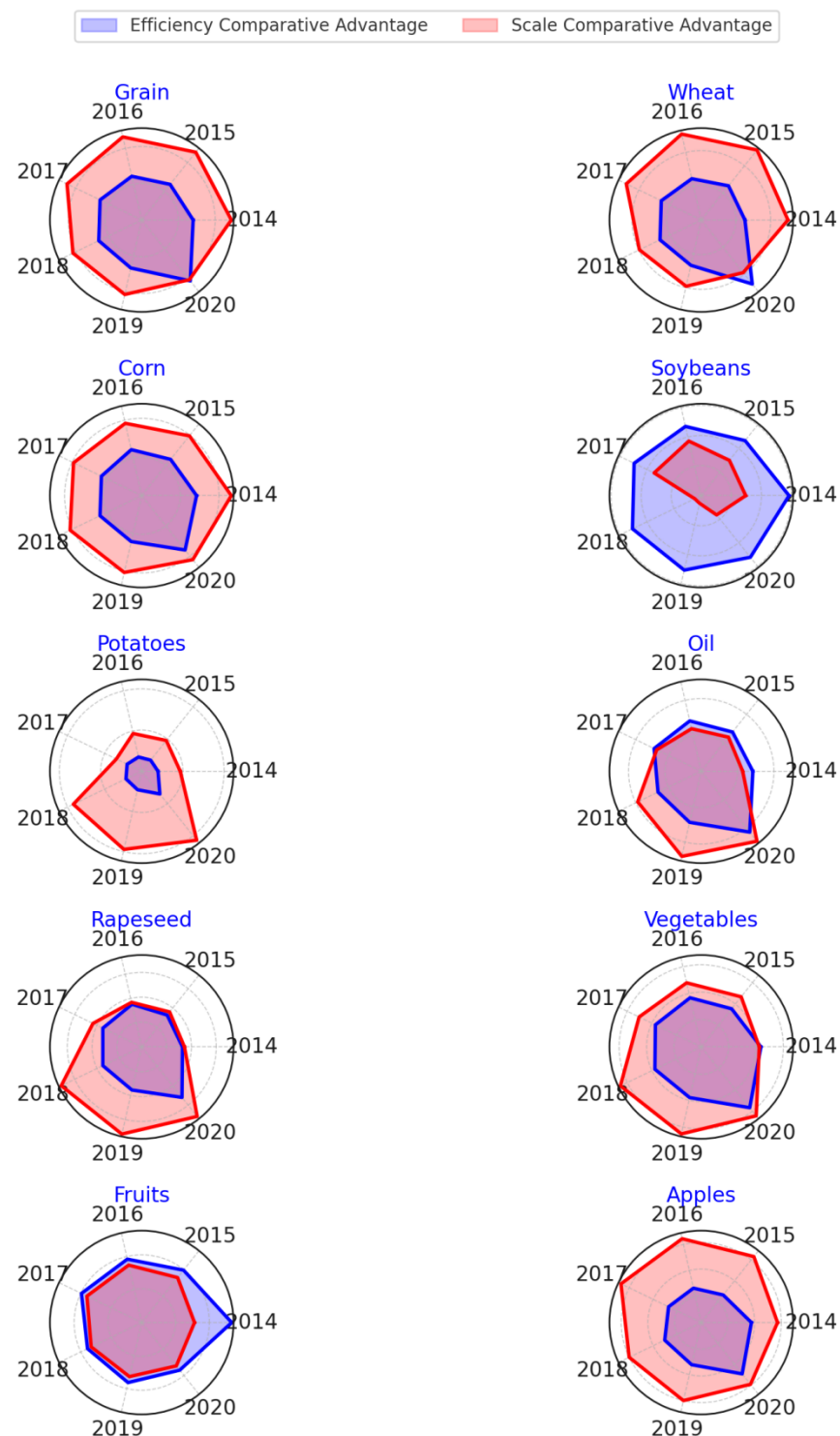


Figure 1. Comparative Advantage Index of Different Agricultural Products in Hancheng City.

Data from Figure 1 show that the Scale Comparative Advantage Index (SCAI) for grains in Hancheng City has been greater than 1 over the seven years, indicating a significant scale comparative advantage. Specifically, the SCAI for wheat was greater than 1 in the first four years but has been less than 1 in the most recent three years, indicating a beginning of a comparative disadvantage. The SCAI for corn has been greater than 1 in the most recent three years, showing stability and a slow upward trend. The SCAI for beans has been less than 1 over the seven years, indicating a comparative disadvantage, but there was a significant increase in 2020. The SCAI for potatoes is the highest and has been over

3.5 in the most recent three years, indicating a significant scale comparative advantage. The SCAI for oilseeds has been on an upward trend and has been greater than 1 in the most recent two years, indicating a beginning of a scale comparative advantage. Specifically, the SCAI for rapeseed has been greater than 1 since 2017, indicating a significant scale comparative advantage. Vegetables in Hancheng City have always shown a significant scale comparative advantage, and this trend is continuously increasing. Although fruit cultivation in Hancheng City does not have a scale comparative advantage, apples have a significant scale comparative advantage. Among all cultivated products, apples show the most significant scale comparative advantage, except for potato crops.

3.1.2. Analysis of the Output Value of Major Crops in Hancheng City

Figure 2 illustrates the annual output value trends of major products in Hancheng City from 2011 to 2020. The following observations can be made:

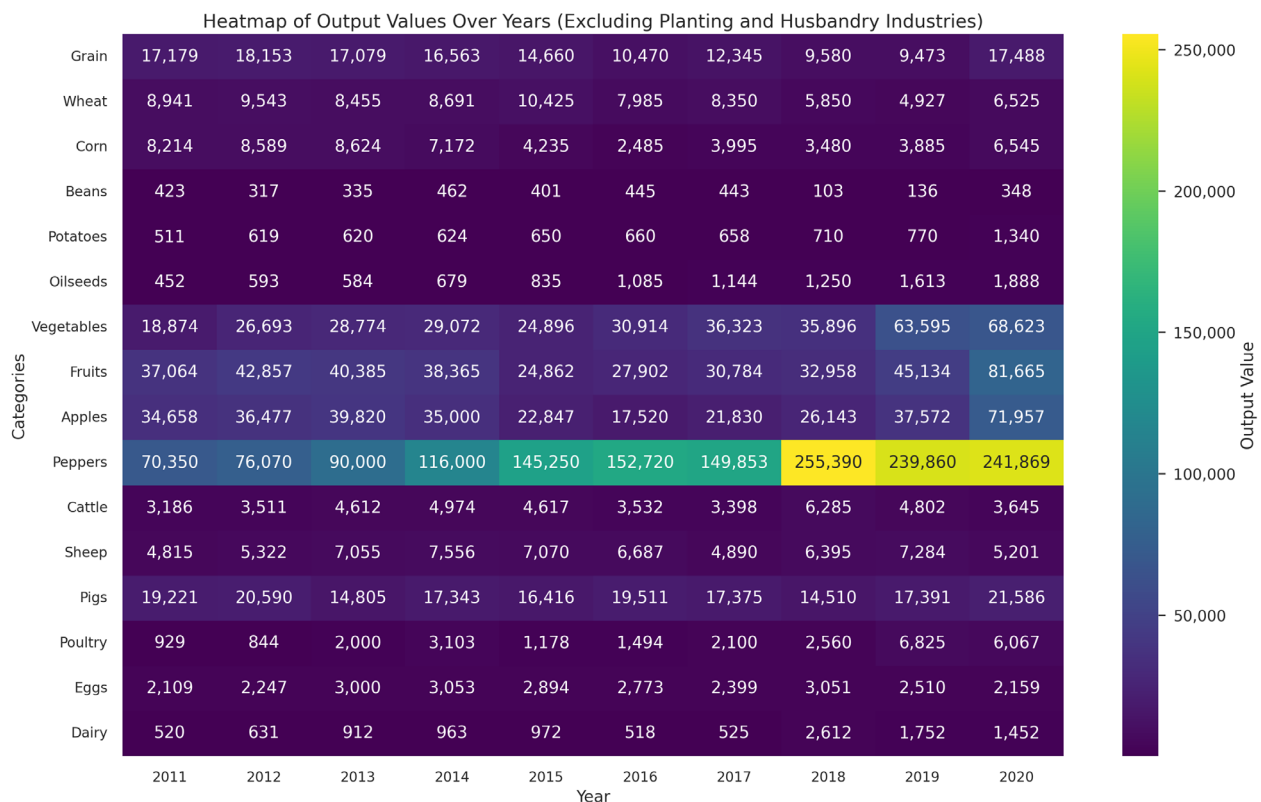


Figure 2. Output value of different agricultural products in Hancheng City.

The output value of the planting industry and pepper has significantly increased, especially for pepper, which grew from 70,350 in 2011 to 241,869 in 2020. This indicates a substantial increase in pepper cultivation and market demand during this period. The output value of vegetables and fruits also saw significant growth, particularly between 2018 and 2020. This growth may be attributed to technological improvements, increased market demand, or policy support. The output value of beans remained relatively low and stable, indicating a steady but limited market growth. The output value of grains, wheat, and corn fluctuated between 2011 and 2017 but showed an overall declining trend, with a slight rebound afterward. This could reflect changes in market demand, climate conditions, or adjustments in planting structures. The output value of oilseeds steadily increased throughout the period, indicating their growing importance in the agricultural economy.

Figure 3 illustrates the correlation between the output values of various products and the total output value of the planting and breeding industries, revealing the following key points:

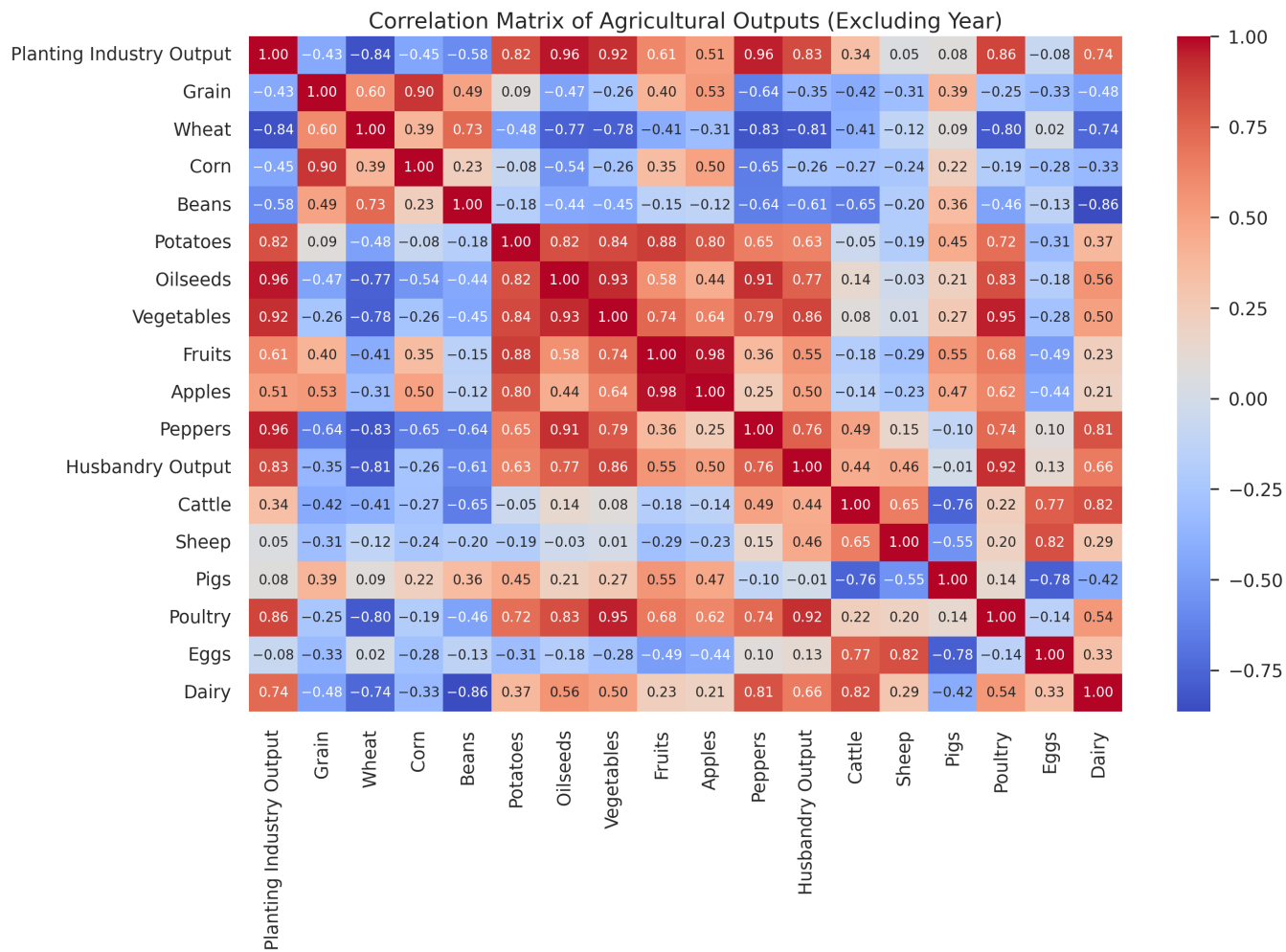


Figure 3. Correlation between output values of different agricultural products in Hancheng City.

The output value of the planting industry has the highest correlation with pepper (close to 1), indicating that pepper contributes the most to the output value of the planting industry. As a high-economic-value crop, the significant increase in the planting area and yield of pepper has notably driven the overall output value growth of the planting industry. Oilseeds, vegetables, and fruits also show high correlations with the output value of the planting industry. These crops perform well in terms of market demand and economic returns, significantly promoting the development of the planting industry. The output value of the breeding industry shows a high correlation with poultry meat and sheep, indicating their importance in the output value of the breeding industry. As major meat products, the stable market demand and relatively low-price fluctuations for poultry meat and sheep have a significant impact on the output value of the breeding industry. Beans and corn have relatively low correlations with the output value of the planting industry, reflecting their lesser economic impact within the planting industry. To enhance their economic contributions, it may be necessary to optimize the planting structure and improve production efficiency.

3.2. Environmental Benefit Analysis of Various Agricultural Products

3.2.1. Spatiotemporal Analysis of Carbon Emissions of Various Agricultural Products

According to Figure 4, the agricultural carbon emission intensity of major agricultural products in Hancheng City, from highest to lowest, is as follows: soybeans > wheat > corn > potatoes > rapeseed > cattle > sheep > pigs > vegetables > poultry > apples > pepper. From the perspective of carbon emission intensity, the production scale of vegetables, poultry,

apples, and pepper should be expanded to achieve higher output values with relatively low carbon emissions.

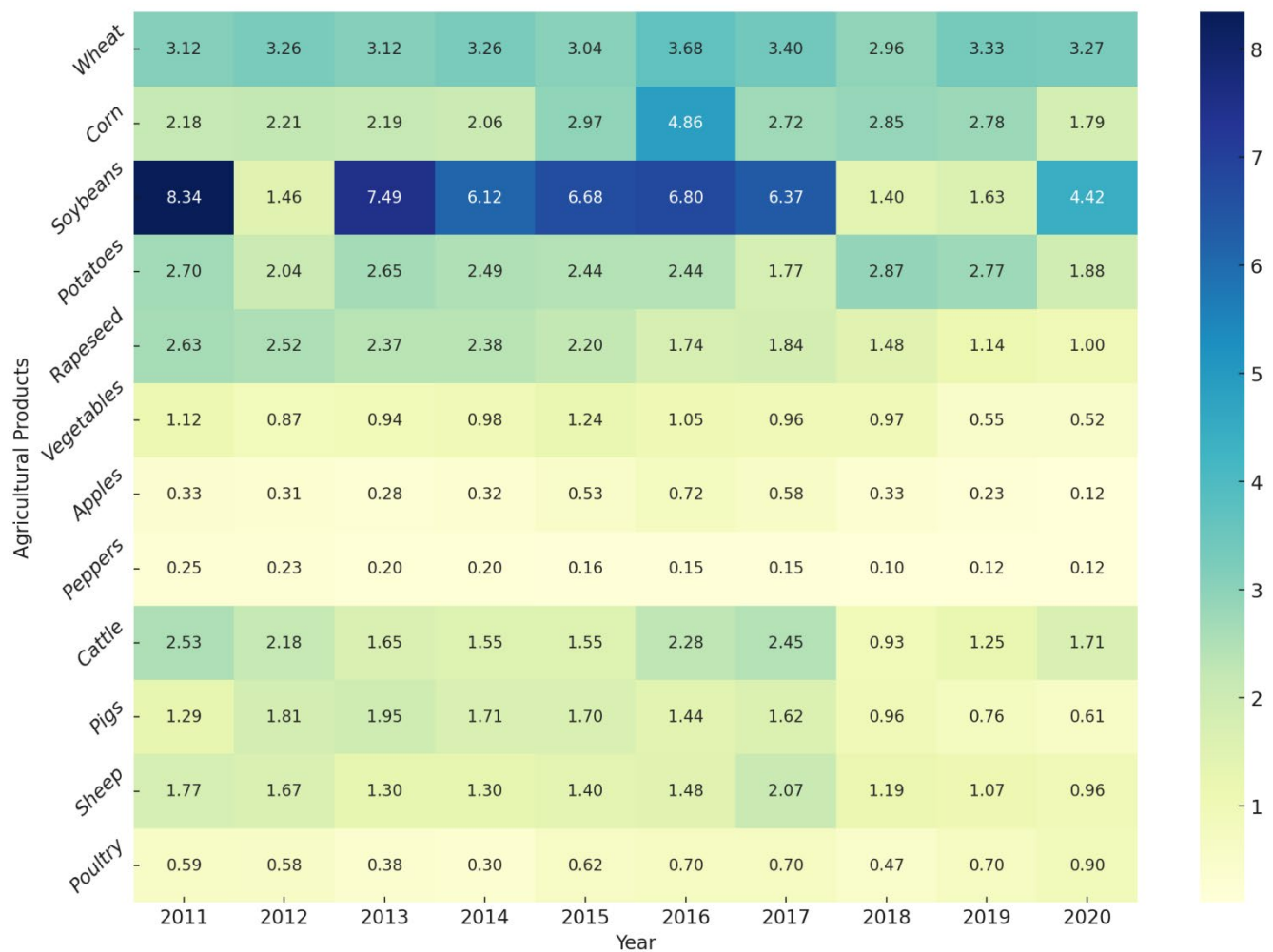


Figure 4. The agricultural carbon emission intensity of major agricultural products in Hancheng City.

In terms of temporal changes, the carbon emission intensity of rapeseed, vegetables, apples, pepper, cattle, pigs, and sheep has shown a general decreasing trend. This may be related to the increasing scale and gradually standardized production methods of these agricultural products. The carbon emission intensity of wheat, corn, soybeans, and potatoes has remained relatively stable. These four crops are fundamental grain or oil crops in China with relatively stable prices, while the prices of agricultural inputs such as fertilizers and pesticides have been rising annually. Therefore, it is essential to reduce carbon emission intensity by optimizing the production technology systems.

According to Figure 5, wheat, corn, vegetable, and pepper cultivation, along with pig farming, are the primary sources of agricultural carbon emissions in Hancheng City, accounting for 75.6% to 79.6% of the total agricultural carbon emissions. From 2011 to 2020, the contributions of wheat cultivation, vegetable cultivation, and pig farming to agricultural carbon emissions remained relatively consistent. However, the contribution rate of corn to carbon emissions gradually declined, decreasing from 12.4% to 8.2%.

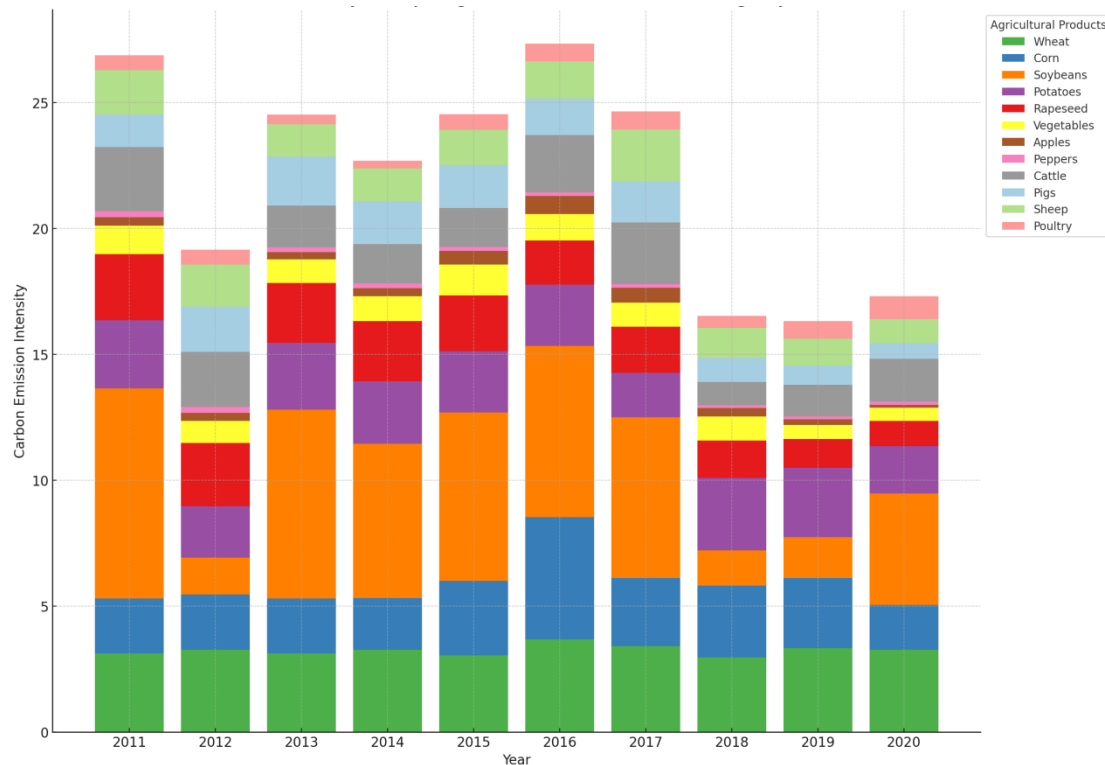


Figure 5. Composition of Agricultural Carbon Emissions in Hancheng City from 2011 to 2020.

After 2018, the carbon emission structure changed significantly, with substantial reductions in carbon emissions due to wheat cultivation and pig farming, decreasing from 28,000 tons and 25,000 tons to 21,000 tons and 14,000 tons, respectively. Subsequently, vegetable cultivation became the dominant source of agricultural carbon emissions, with its share increasing from 14.6% to 25.1% by 2020.

Over the decade, the contributions of potatoes and poultry to carbon emissions increased annually. The carbon emissions from potato cultivation rose from 1379 tons to 2518 tons, an 82.6% increase, raising its share of agricultural carbon emissions from 1.0% to 1.8%. This increase was mainly due to the expanded planting area of potatoes and the corresponding rise in energy consumption. Poultry farming emissions remained stable before 2014 but increased yearly afterward. The significant development of Fuqiang Hongtu Animal Husbandry Co., Ltd. in Hancheng City between 2014 and 2020 marked the growth in poultry farming carbon emissions. By 2020, poultry farming emissions had increased threefold from 1873 tons to 7422 tons, raising its share from 1.2% to 5.2%.

Corn cultivation experienced a trend of initial decrease followed by an increase in carbon emissions. Early reductions were influenced by urban construction and the North Forest Project, leading to decreased corn planting areas. Standardized field management techniques improved crop yields while reducing fertilizer and pesticide use, contributing to decreased emissions. In recent years, to ensure food security and maintain staple crop yields, the government encouraged the cultivation of corn and wheat, resulting in increased carbon emissions due to expanded planting areas.

Apple carbon emissions initially increased, reaching a peak of 12,611 tons in 2016, before declining to a seven-year low of 8589 tons in 2020, a 31.9% reduction. The decrease in apple carbon emissions was due to two main factors: the Hancheng City government's efforts to improve agricultural production efficiency and optimize the agricultural industry layout by adjusting the industrial structure based on resource endowments and market changes, reducing non-optimal apple planting areas in favor of peaches, walnuts, and persimmons. Additionally, the Hancheng City Fruit Industry Technology Promotion Center

provided technical guidance to local farmers, standardizing orchard management and reducing waste of agricultural materials.

3.2.2. Decomposition Results and Analysis of Factors Influencing Agricultural Carbon Emissions in Hancheng City

The LMDI decomposition results are shown in Figure 6. The overall carbon emissions in Hancheng City decreased from 2011 to 2020. However, the data for each year indicate that reductions were achieved in 2012–2014 and 2017–2018, while in other years, agricultural carbon emissions increased.

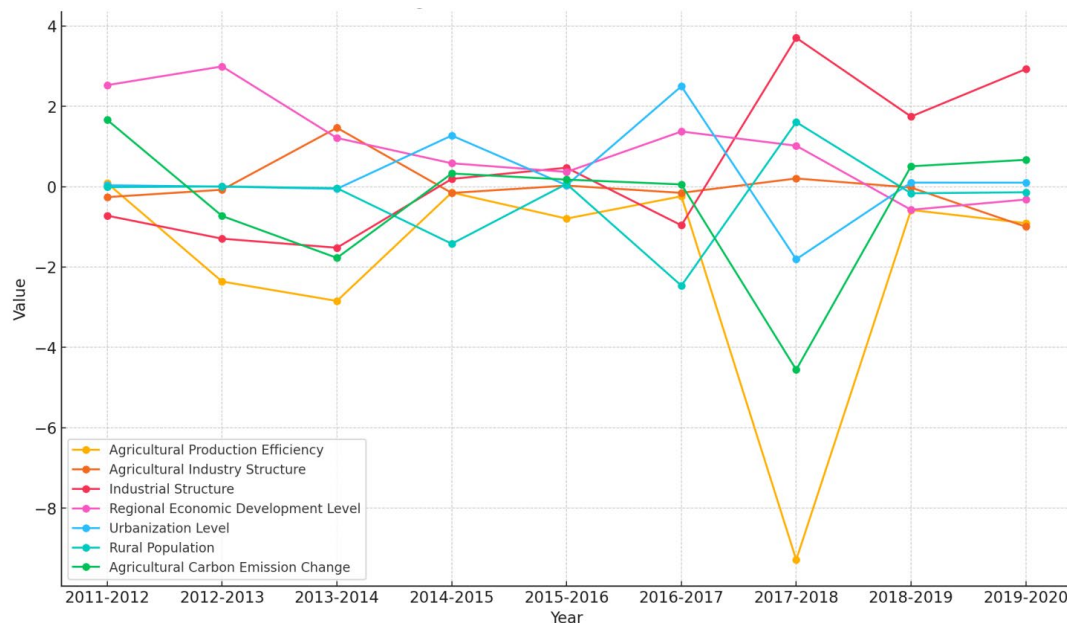


Figure 6. The LMDI decomposition in Hancheng City.

Among the different influencing factors, agricultural production efficiency has a significant emission reduction effect. From 2011 to 2020, the cumulative emission reduction was 170,700 tons, with an average annual reduction of 19,000 tons. The data indicate that agricultural production efficiency positively drives agricultural carbon reduction. In recent years, the government of Hancheng City has actively developed agricultural infrastructure, constructed high-standard farmland, and implemented integrated water and fertilizer projects, effectively improving agricultural production efficiency.

Agricultural structure has a positive impact on agricultural carbon emissions, but the effect is relatively small. From 2011 to 2020, the agricultural structure in Hancheng City increased agricultural carbon emissions by 370 tons, indicating a low impact of agricultural structure on carbon emissions. According to the annual changes in carbon emissions, the variations in annual carbon emissions from 2011 to 2019 were relatively small, indicating a stable agricultural industry structure in Hancheng City. The geographical environment of Hancheng City, characterized as “seven parts mountains, one part water, and two parts farmland”, has formed a unique agricultural structure. The western part of Hancheng is mostly mountainous and hilly, primarily developing forestry and animal husbandry, focusing on economic crops such as pepper and fruit trees. The eastern part is relatively flat, adjacent to the Yellow River, serving as the main production area for grains, oils, and vegetables, and is also the main urban concentration area. Large-scale adjustments to the agricultural structure are difficult, hence the structure remains relatively stable.

Changes in industrial structure and regional economic factors have increased agricultural carbon emissions. From 2011 to 2020, changes in industrial structure increased carbon emissions by 45,520 tons, with an average annual carbon emission of 5050 tons. Regional economic factors cumulatively contributed 91,870 tons of carbon emissions, with

an average annual carbon emission of 10,187 tons. This is mainly due to the development of agricultural technology and regional economic development levels, where agricultural mechanization gradually covered agricultural production. The construction of large-scale agricultural water facilities created favorable conditions for agricultural production. Meanwhile, Hancheng City strengthened its grain self-sufficiency capability, improved the capacity for stable production and supply of key agricultural products, addressed shortcomings in agriculture, rural areas, and farmers, and encouraged the city to produce grains, vegetables, and meat products. Measures such as intercropping, multiple cropping, and reclamation of idle land increased the planting area of corn and wheat. The city supported the development of facility agriculture, greatly promoting the cultivation of facility vegetables to meet the consumption needs of residents. The city also expanded the scale of pig farming and vigorously developed poultry and fish farming to ensure the supply of meat products, thereby enhancing agricultural carbon emissions.

Urbanization level is also a major factor in increasing agricultural carbon emissions. From 2011 to 2020, urbanization factors in Hancheng City cumulatively produced 21,930 tons of agricultural carbon emissions, positively affecting agricultural carbon emissions. Since Hancheng City was listed as a national pilot for new urbanization in 2015, the pace of urbanization in Hancheng has accelerated further. The city vigorously promoted the construction of old urban areas and the renovation of shantytowns, realizing the spatial reconstruction of villages. Some villages were relocated from remote mountainous areas to plains, promoting housing construction and village infrastructure, further increasing agricultural carbon emission levels.

Rural population has a negative impact on agricultural carbon emissions. From 2011 to 2020, agricultural labor factors cumulatively reduced agricultural carbon emissions by 25,490 tons. This aligns with the fact that Hancheng City has been conducting vocational training classes for farmers, improving the vocational quality of farmers in recent years. The improvement in farmers' quality has enhanced their understanding of green and efficient agriculture, allowing them to use fertilizers and pesticides more scientifically in agricultural production, achieving the effect of reducing quantity while increasing efficiency. They can also apply new planting models to improve agricultural production efficiency, thereby reducing agricultural carbon emissions.

3.3. Comprehensive Advantage Index Analysis

Figure 7 displays the comprehensive advantage index, average output value, and average unit output value carbon emission intensity for each agricultural product. The horizontal axis represents the average output value of each product, the vertical axis represents the average unit output value carbon emission intensity, and the color of the dots represents the comprehensive advantage index, with colors gradually transitioning from purple to yellow, indicating an increase in the comprehensive advantage index from low to high.

(1) Pepper

- Economic Benefits: pepper has the highest average output value among all agricultural products, demonstrating significant economic advantages.
- Environmental Benefits: pepper has one of the lowest unit output value carbon emission intensities, indicating excellent environmental benefits.
- Comprehensive Advantage: Pepper has the highest comprehensive advantage index, with the color close to yellow, indicating that pepper has significant advantages in terms of both economic and environmental benefits. It is recommended to focus on the development of pepper, further optimizing its cultivation and management techniques to maximize its economic and environmental benefits.

(2) Soybeans

- Economic Benefits: soybeans have a relatively low average output value, indicating a disadvantage in economic benefits.

- Environmental Benefits: soybeans have the highest unit output value carbon emission intensity, indicating a significant disadvantage in environmental benefits.
 - Comprehensive Advantage: Soybeans have the lowest comprehensive advantage index, with the color close to purple, indicating that soybeans need improvement in terms of both economic and environmental benefits. It is recommended to improve cultivation techniques and management measures to reduce the carbon emission intensity of soybeans and enhance their comprehensive advantage.
- (3) Vegetables
- Economic Benefits: vegetables have a relatively high average output value, indicating good economic benefits.
 - Environmental Benefits: vegetables have a low unit output value carbon emission intensity, indicating an advantage in environmental benefits.
 - Comprehensive Advantage: Vegetables have a relatively high comprehensive advantage index, with the color close to neutral, indicating good performance in terms of both economic and environmental benefits. It is recommended to further develop vegetable cultivation, promoting advanced cultivation techniques to increase yield and reduce carbon emissions.
- (4) Wheat
- Economic Benefits: wheat's average output value and unit output value carbon emission intensity are both in the middle range, indicating moderate economic and environmental benefits.
 - Environmental Benefits: wheat has a moderate unit output value carbon emission intensity, indicating fair environmental benefits.
 - Comprehensive Advantage: Wheat has a moderate comprehensive advantage index, with the color in the middle range, indicating a balance between economic and environmental benefits. It is recommended to continue improving the cultivation and management techniques of wheat to enhance its comprehensive benefits.

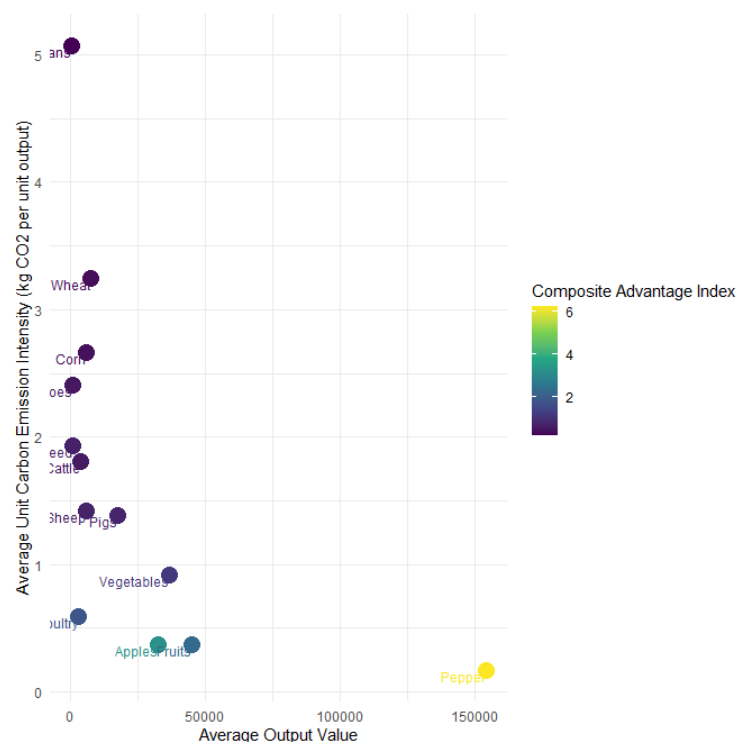


Figure 7. Comprehensive Advantage Index of major agricultural products in Hancheng City.

4. Discussion and Policy Implications

4.1. Implications for Management from Research Findings

This study comprehensively evaluated the environmental and economic benefits of agricultural products, revealing the performance of major agricultural products in Hancheng City in terms of sustainable development. The results show that pepper has the highest comprehensive advantage index, indicating outstanding performance in terms of both economic and environmental benefits, making it a highly suitable product for further development. Vegetables also exhibit a high comprehensive advantage, demonstrating a balance in economic and environmental benefits, suitable for large-scale promotion and cultivation. In contrast, soybeans have a lower comprehensive advantage, characterized by high carbon emission intensity and lower economic benefits, indicating a need for improvement in cultivation techniques and management practices [23].

Compared to the existing literature, the results of this study differ in some aspects [24,25]. For instance, pepper has the highest comprehensive advantage index in this study, whereas, in other studies, its performance may vary due to differences in research areas and methods [26–28]. The performance of vegetables in this study is also superior to that in many other regions, likely due to the unique climatic conditions and soil characteristics of Hancheng City. Additionally, this study found that the carbon emission intensity of soybeans is high, consistent with some studies that assess the high environmental costs of soybeans [29–31]. These differences may stem from variations in agricultural practices and management methods in different regions. Therefore, agricultural development strategies for different regions need to be adjusted and optimized based on local specific conditions and research findings [32–34].

Based on the results of this study, we propose the following policy and management recommendations for the agricultural development of Hancheng City:

1. **Focus on Developing High Comprehensive Advantage Agricultural Products:** Pepper and vegetables show high comprehensive advantages and are recommended as key agricultural products for development. The government should increase support for these crops, including funding, technology promotion, and market development.
2. **Improve Cultivation Techniques for Low Comprehensive Advantage Agricultural Products:** For agricultural products like soybeans with lower comprehensive advantages, measures should be taken to improve their cultivation techniques and management practices, reduce their carbon emission intensity, and increase production efficiency. Specific measures include promoting low-carbon cultivation techniques, optimizing fertilization and irrigation methods, and introducing high-efficiency, low-consumption agricultural machinery.
3. **Promote Green Agricultural Technologies:** The government should enhance the promotion of green agricultural technologies, improving farmers' environmental awareness and technical skills. For example, through training and demonstration projects, the use of organic fertilizers, green pest control technologies, and water-saving irrigation techniques should be promoted.
4. **Establish a Carbon Footprint Monitoring System for Agricultural Products:** To better understand and manage agricultural carbon emissions, it is recommended to establish a city-wide carbon footprint monitoring system for agricultural products. By continuously monitoring and evaluating the carbon emissions of different agricultural products, data support can be provided for formulating scientific carbon reduction policies.
5. **Strengthen Agricultural Infrastructure Construction:** Improve agricultural infrastructure construction to enhance the modernization level of agricultural production. For instance, building high-standard farmland, improving water conservancy facilities, and promoting smart agricultural technologies can improve agricultural production efficiency and sustainability.
6. **Promote Agricultural Product Branding and Market Development:** Through brand building and market development, the market competitiveness and added value

of high comprehensive advantage agricultural products like pepper and vegetables should be increased. The government should support the branding of agricultural products, explore domestic and international markets, and increase farmers' income.

4.2. Limitations and Future Directions

This study reveals the performance of major agricultural products in Hancheng City in terms of economic and environmental benefits, but it also has some limitations that point to directions for future research. Below are the detailed limitations and proposed future directions:

1. Data Acquisition and Processing Limitations:

The reliance on limited data sources may lead to potential inaccuracies or incompleteness in the carbon emission data for certain agricultural products, affecting the overall assessment results. Future research should aim to expand data sources to obtain more comprehensive and accurate carbon emission data. This can be achieved by collaborating with more agricultural production units and research institutions to establish a broader data-sharing network.

2. Carbon Emissions Consideration:

This study only considers carbon emissions during the production process of agricultural products and does not account for emissions during transportation and processing stages. This may result in a less comprehensive assessment. Future research should consider carbon emissions across all stages of the agricultural product lifecycle, including production, transportation, processing, and consumption, to provide a more holistic environmental impact assessment.

3. Regional Applicability:

The unique climatic conditions and soil characteristics of Hancheng City contribute to the outstanding performance of agricultural products in this study. However, these characteristics also mean that the study's findings need to be applied cautiously in other regions. Different regions' climates, soils, and agricultural practices can significantly influence the economic and environmental benefits of agricultural products. When applying the conclusions of this study to other regions, it is essential to consider these regional differences.

4. Future Research Directions:

Future research should explore the comprehensive advantages of agricultural products in various regions and climates to develop more targeted agricultural development and carbon reduction strategies. Comparative studies across different regions can offer valuable insights and help formulate agricultural policies and management practices that cater to the specific needs of each region.

Additionally, future research should consider the impact of agricultural technology advancements and policy changes on the comprehensive advantages of agricultural products. As agricultural technologies continue to evolve and the policy environment changes, the economic and environmental benefits of agricultural products may also change. Continuous monitoring and evaluation of these changes and adjustments based on the latest technologies and policies are essential for ensuring sustainable agricultural development.

5. Conclusions

This study conducted a comprehensive analysis of the economic and environmental benefits of major agricultural products in Hancheng City, resulting in the calculation of the comprehensive advantage index for each product. The results show that pepper stands out in terms of both economic and environmental benefits, having the highest comprehensive advantage index, and is recommended as a key focus for development. Vegetables also exhibit a good comprehensive advantage, demonstrating a balance in economic and environmental benefits, making them suitable for further promotion and

development. Conversely, soybeans show lower economic and environmental benefits and need improvements in cultivation techniques and management practices to enhance their comprehensive advantage. Wheat shows moderate performance in terms of both economic and environmental benefits, indicating a certain balance, and requires maintenance and optimization of its cultivation and management. Overall, this study provides scientific data support, revealing the performance of different agricultural products in terms of economic and environmental benefits, offering important references for the agricultural development strategy of Hancheng City. It is recommended that Hancheng City focus on developing agricultural products with high comprehensive advantages, such as pepper and vegetables, while implementing technical improvement measures for products with lower comprehensive advantages, such as soybeans, to achieve sustainable agricultural development and carbon reduction goals. This comprehensive evaluation method helps formulate more balanced and sustainable agricultural policies, providing strong support for achieving carbon neutrality goals. The comprehensive evaluation method proposed in this study is crucial for developing agricultural policies that simultaneously address economic viability and environmental sustainability, thereby contributing to the broader goal of carbon neutrality.

Author Contributions: Conceptualization, C.L. and H.W.; methodology, C.L.; software, C.L.; validation, H.W. and C.L.; formal analysis, C.L.; investigation, Z.Z.; writing—original draft preparation, X.L.; writing—review and editing, Z.Z.; funding acquisition, X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the General Project of Shaanxi Key Research and Development Plan (2022NY-059).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: Thank the reviewers and editors for their insightful suggestions to the manuscript that improved the quality of the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Wei, S.; Yang, Y.; Xu, Y. Regional development, agricultural industrial upgrading and carbon emissions: What is the role of fiscal expenditure?—Evidence from Northeast China. *Econ. Anal. Policy* **2023**, *80*, 1858–1871. [\[CrossRef\]](#)
2. Elahi, E.; Zhu, M.; Khalid, Z.; Wei, K. An empirical analysis of carbon emission efficiency in food production across the Yangtze River basin: Towards sustainable agricultural development and carbon neutrality. *Agric. Syst.* **2024**, *218*, 103994. [\[CrossRef\]](#)
3. Yang, X.; Liu, Y.; Bezama, A.; Thrän, D. Agricultural carbon emission efficiency and agricultural practices: Implications for balancing carbon emissions reduction and agricultural productivity increment. *Environ. Dev.* **2024**, *50*, 101004. [\[CrossRef\]](#)
4. Chen, X.; Zhen, S.; Li, S.; Yang, J.; Ren, Y. Consumers' willingness to pay for carbon-labeled agricultural products and its effect on greenhouse gas emissions: Evidence from beef products in urban China. *Environ. Impact Assess.* **2024**, *106*, 107528. [\[CrossRef\]](#)
5. Zhang, L.; Cai, C.; Singh, K.; Zhong, K. Green technology innovation, trade deficit and carbon emission transfer in agriculture under the new "dual circulation" development pattern of China. *Ecol. Indic.* **2024**, *159*, 111757. [\[CrossRef\]](#)
6. Ji, M.; Li, J.; Zhang, M. What drives the agricultural carbon emissions for low-carbon transition? Evidence from China. *Environ. Impact Assess.* **2024**, *105*, 107440. [\[CrossRef\]](#)
7. Li, G.; Huang, Y.; Peng, L.; You, J.; Meng, A. Agricultural carbon reduction in China: The synergy effect of trade and technology on sustainable development. *Environ. Res.* **2024**, *252*, 119025. [\[CrossRef\]](#) [\[PubMed\]](#)
8. Wang, D.; Chen, C.; Zhu, N.; Xu, X. Impact of agricultural digitalization on carbon emission intensity of planting industry: Evidence from China. *Heliyon* **2024**, *10*, e31215. [\[CrossRef\]](#) [\[PubMed\]](#)
9. Wang, J.; Peng, L.; Chen, J.; Deng, X. Impact of Rural Industrial Integration on Farmers' Income: Evidence from Agricultural Counties in China. *J. Asian Econ.* **2024**, *93*, 101761. [\[CrossRef\]](#)
10. Liu, W.; Liu, S.; Liu, S. Coupling coordination analysis of population, economy and grain in major grain-producing counties. *Heliyon* **2024**, *10*, e23869. [\[CrossRef\]](#)

11. Li, L.; Han, J.; Zhu, Y. Does environmental regulation in the form of resource agglomeration decrease agricultural carbon emissions? Quasi-natural experimental on high-standard farmland construction policy. *J. Clean. Prod.* **2023**, *420*, 138342. [\[CrossRef\]](#)
12. Zhao, L.; Rao, X.; Lin, Q. Study of the impact of digitization on the carbon emission intensity of agricultural production in China. *Sci. Total Environ.* **2023**, *903*, 166544. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Hou, M.; Cui, X.; Xie, Y.; Lu, W.; Xi, Z. Synergistic emission reduction effect of pollution and carbon in China's agricultural sector: Regional differences, dominant factors, and their spatial-temporal heterogeneity. *Environ. Impact Assess.* **2024**, *106*, 107543. [\[CrossRef\]](#)
14. Litskas, V.D.; Platis, D.P.; Anagnostopoulos, C.D.; Tsaboula, A.C.; Menexes, G.C.; Kalburtji, K.L.; Stavrinides, M.C.; Mamolos, A.P. Chapter 3—Climate change and agriculture: Carbon footprint estimation for agricultural products and labeling for emissions mitigation. In *Sustainability of the Food System*; Betoret, N., Betoret, E., Eds.; Academic Press: Cambridge, MA, USA, 2020; pp. 33–49.
15. Zhang, L.; Cai, C. Innovative measurement, trade-off-synergy relationship and influencing factors for agricultural net carbon emissions and effective supply of agricultural products in China. *Heliyon* **2024**, *10*, e24621. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Liu, L.; Hu, X.; Li, L.; Sun, Z.; Zhang, Q. Understanding China's agricultural non-carbon-dioxide greenhouse gas emissions: Subnational insights and global trade dynamics. *Environ. Impact Assess.* **2024**, *106*, 107487. [\[CrossRef\]](#)
17. Liu, Y.; Zhu, J. Spatial restructuring and population shrinkage along with industrialization in counties: The case of Jiangsu Province. *Habitat Int.* **2023**, *135*, 102785. [\[CrossRef\]](#)
18. Zhou, M.; Shao, W.; Jiang, K.; Huang, L. How does economic agglomeration affect carbon emissions at the county level in Liaoning China? *Ecol. Indic.* **2024**, *158*, 111507. [\[CrossRef\]](#)
19. Cai, Z.; Hu, L.; Chen, D.; Zhang, Y.; Fang, X. Structural characteristics and drivers of greenhouse gas emissions at county-level and long-time scales: A case study of the Anji County, China. *J. Environ. Sci. China* **2024**, *140*, 319–330. [\[CrossRef\]](#) [\[PubMed\]](#)
20. Zhang, Z.; Du, J.; Shen, Z.; El Asraoui, H.; Song, M. Effects of modern agricultural demonstration zones on cropland utilization efficiency: An empirical study based on county pilot. *J. Environ. Manag.* **2024**, *349*, 119530. [\[CrossRef\]](#)
21. Cai, A.; Guo, R.; Zhang, Y.; Wu, J. Status and trends of carbon emissions research at the county level in China. *Adv. Clim. Chang. Res.* **2024**, *15*, 338–352. [\[CrossRef\]](#)
22. Zhang, Y.; Wang, J.; Zhang, M.; He, C. The mechanism of revoking counties or county-level cities to municipal districts and its effect on urban expansion in Chinese cities. *Appl. Geogr.* **2023**, *159*, 103068. [\[CrossRef\]](#)
23. Xu, Z.; Li, F.; Cheng, J.; Liang, Z.; Groot, J.C.J.; van der Werf, W.; Zhang, C. Survey data on livelihoods and inputs and outputs of crop production in Quzhou county on the North China Plain. *Data Brief* **2024**, *53*, 110269. [\[CrossRef\]](#)
24. Sharafi, S.; Kazemi, A.; Amiri, Z. Estimating energy consumption and GHG emissions in crop production: A machine learning approach. *J. Clean. Prod.* **2023**, *408*, 137242. [\[CrossRef\]](#)
25. Liang, J.; Pan, S.; Xia, N.; Chen, W.; Li, M. Threshold response of the agricultural modernization to the open crop straw burning CO₂ emission in China's nine major agricultural zones. *Agric. Ecosyst. Environ.* **2024**, *368*, 109005. [\[CrossRef\]](#)
26. Kantwa, S.R.; Choudhary, M.; Agrawal, R.K.; Dixit, A.K.; Kumar, S.; Chary, G.R. Reducing energy and carbon footprint through diversified rainfed cropping systems. *Energy Nexus* **2024**, *14*, 100306. [\[CrossRef\]](#)
27. Kargwal, R.; Yadvika, K.; Kumar, A.; Garg, M.K.; Chanakaewsomboon, I. A review on global energy use patterns in major crop production systems. *Environ. Sci. Adv.* **2022**, *1*, 662–679. [\[CrossRef\]](#)
28. Yang, Y.; Xiao, C.; Wang, F.; Peng, L.; Zeng, Q.; Luo, S. Assessment of the potential for phytoremediation of cadmium polluted soils by various crop rotation patterns based on the annual input and output fluxes. *J. Hazard. Mater.* **2022**, *423*, 127183. [\[CrossRef\]](#)
29. Bista, D.; Sapkota, S.; Acharya, P.; Acharya, R.; Ghimire, R. Reducing energy and carbon footprint in semi-arid irrigated cropping systems through crop diversification. *Heliyon* **2024**, *10*, e27904. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Cai, R.; Ma, J.; Wang, S.; Cai, S. Can crop insurance help optimize farmers' decisions on pesticides use? Evidence from family farms in East China. *J. Asian Econ.* **2024**, *92*, 101735. [\[CrossRef\]](#)
31. Kan, I.; Reznik, A.; Kaminski, J.; Kimhi, A. The impacts of climate change on cropland allocation, crop production, output prices and social welfare in Israel: A structural econometric framework. *Food Policy* **2023**, *115*, 102311. [\[CrossRef\]](#)
32. Ojeda, J.J.; Rezaei, E.E.; Remenyi, T.A.; Webber, H.A.; Siebert, S.; Meinke, H.; Webb, M.A.; Kamali, B.; Harris, R.M.B.; Kidd, D.B.; et al. Implications of data aggregation method on crop model outputs—The case of irrigated potato systems in Tasmania, Australia. *Eur. J. Agron.* **2021**, *126*, 126276. [\[CrossRef\]](#)
33. Oberson, A.; Jarosch, K.A.; Frossard, E.; Hammelehle, A.; Fliessbach, A.; Mäder, P.; Mayer, J. Higher than expected: Nitrogen flows, budgets, and use efficiencies over 35 years of organic and conventional cropping. *Agric. Ecosyst. Environ.* **2024**, *362*, 108802. [\[CrossRef\]](#)
34. Sanford, G.R.; Jackson, R.D.; Booth, E.G.; Hedtcke, J.L.; Picasso, V. Perenniality and diversity drive output stability and resilience in a 26-year cropping systems experiment. *Field Crops Res.* **2021**, *263*, 108071. [\[CrossRef\]](#)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.